DOCUMENT HISTORY:

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SUMMARY

Since 1991, Quartzdyne has introduced several models of quartz pressure transducers and custom hybrid circuits to the downhole market. Prior to releasing any product for manufacture, for the downhole market, Quartzdyne subjects prototypes to a suite of environmental tests. As part of the verification process in the design phase, environmental testing helps to identify design weaknesses and creates added confidence in the robustness of the product, should it survive. In addition, product designs (for both transducers and hybrids) are occasionally re-qualified to justify the implementation of new components, changes in existing components, soldering technique, circuit mounting, and die attach methods. The current suite of environmental tests Quartzdyne employs include Random Vibration, Heated Random Vibration, Sine Sweep, Shock, Drop Shock, Thermal Shock, and more recently Highly Accelerated Life Testing (HALT). The following are typical test levels for each of the previously stated tests. (There is some variation in the tests depending upon the particular testing facility used and their respective capabilities.)

Qualification Testing

1. Thermal Shock: -55° to 150°C, 25 one hour cycles
2. Random Vibration: 10 – 2000 Hz, 15 grms or 10-500 Hz, 20 grms, 15 minutes
3. Sine Sweep: 10-2000 Hz, 10 g, 10 minute sweep, 5 minute dwell at any noted resonances
4. Low Level Shock: 40 g, 11 ms half-sine, 20 bi-directional shocks
5. Drop Shock: 500 g, 2 ms half-sine, 25 drops

Design Phase Testing

1. HALT
2. Quartzdyne Drop Test

As a general practice, temperature and pressure frequencies for transducers are sampled before and after each test. For Hybrid circuits, the current draw and general functionality is ascertained before and after testing. To date, all products have survived a battery of environmental testing, or have been redesigned until survival was achieved.

In addition to the suite of environments listed above, Quartzdyne will also test to a customer's specific environmental requirements for custom or standard transducers and electronics. Ideally, all test environments, excluding HALT, would be built around measured downhole conditions.

THERMAL SHOCK

Quartzdyne environmental testing, when considering items 1-5 listed in the Summary, typically begins with a Thermal Shock test. The argument to perform this test first is to attempt to induce thermal fatigue or thermal stress into the product before it experiences shock and vibration.

Thermal shocking is typically done using a forced air thermal shock chamber, where the upper chamber is kept at 150°C and lower chamber is kept at -55°C. Pressure transducers are attached to an elevator carriage, which moves between chambers in less than five seconds. In the heating and cooling phases, the exterior of the transducer is heated/cooled to 90% of the setpoint within five minutes (37°C/minute or faster). 25 cycles are completed, each cycle lasting approximately one hour.

RANDOM VIBRATION

Random Vibration is an environmental test that is often tailored, at Quartzdyne, for a specific transducer or downhole application. Random Vibration, in general, is performed in three orthogonal axes. Most Random Vibration testing, since 2010, has been coupled with high temperature to increase the severity of the environment. The yield strength of all common materials decreases with increasing temperature and elevated temperatures better represent downhole conditions. Testing temperatures typically range from 150°C to 230°C depending upon equipment capability and product being tested.

The frequency range or bandwidth of the test can also vary. Generally, frequencies up to 2000 Hz are tested, however if the product is targeted for the drilling sector the bandwidth will be limited to 500 Hz with the same grms level. This targets the acceleration energy at the lower frequencies drillers are more interested in.

Along with the bandwidth and temperature parameters, the duration of the test is often increased to induce a greater level of fatigue. Although 15 minutes is a good baseline or minimum target, test durations can be upwards of two hours per axis. The duration is typically determined by good engineering judgment, schedule, and cost.

Figure 1 below shows a typical 10-2000 Hz Random Vibration profile. Figure 2 shows a typical 10-500 Hz profile. Generally the attempt is made to capture as much low frequency energy as possible for which the testing equipment is capable of. All electrodynamic shakers, due to stroke limitations, are limited at the lower frequencies.

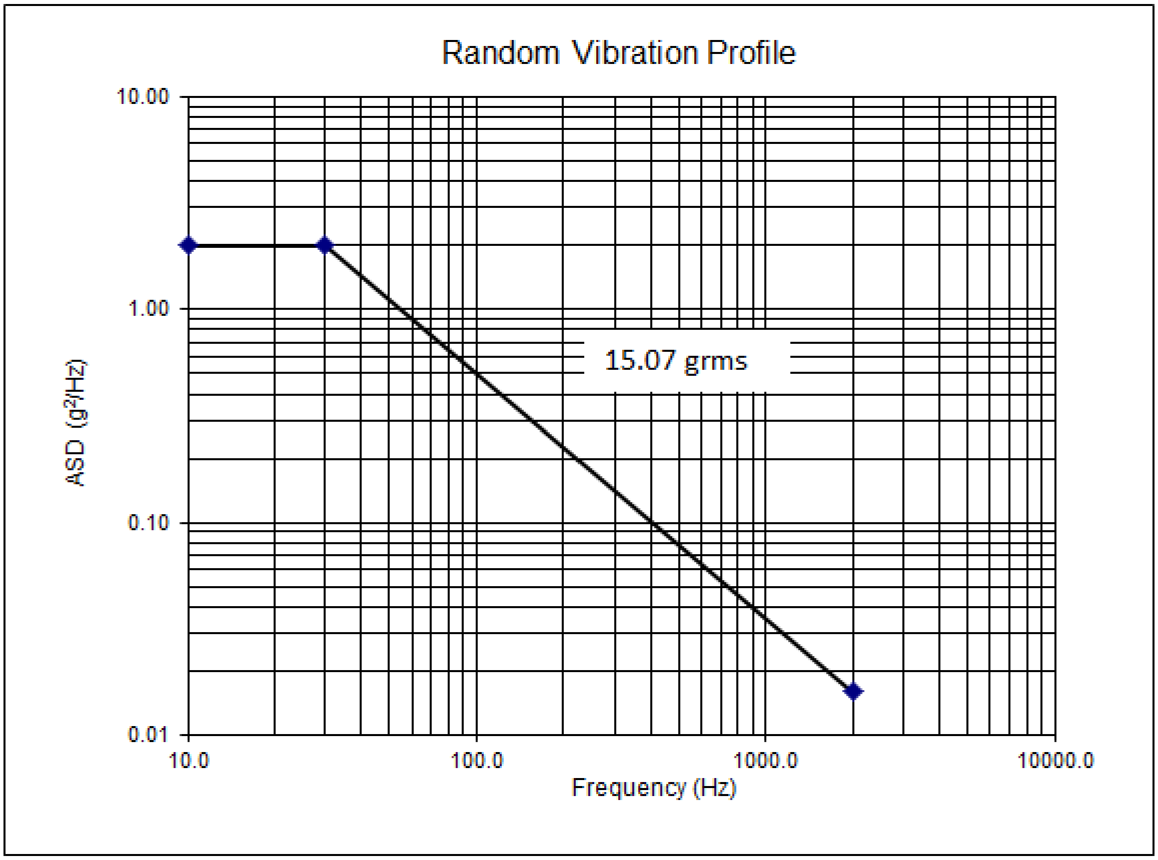


Figure 1. Typical 2000 Hz Random Vibration Profile

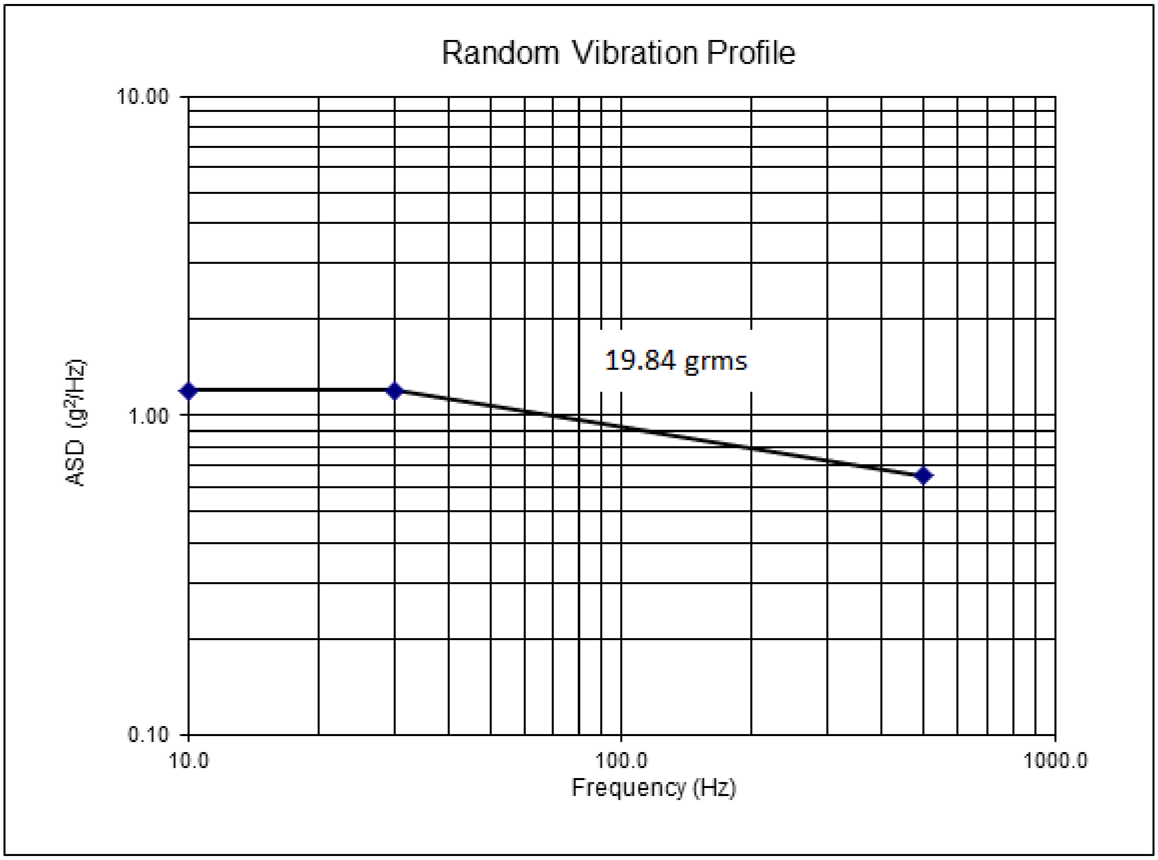


Figure 2. Typical 500 Hz Random Vibration Profile

The traditional axes of a pressure transducer, for reference, are defined as shown below in Figure 3. Isolated Hybrid circuits, although not explicitly defined, can adopt the same coordinate system for test purposes, which is consistent with Figure 4.

Figure 3. DXB012/SPB112 Series Pressure Transducer

Table 1 shows pictures of a typical test setup for a Random Vibration test. The large block the fixture is mounted to provides the ability to vibrate in three orthogonal directions when the block is mounted directly to the shaker head. In this configuration the shaker is able to achieve higher levels of vibration because it doesn't have to vibrate the slip table.

Table 1. X, Y, and Z Axis Random Vibe Setup

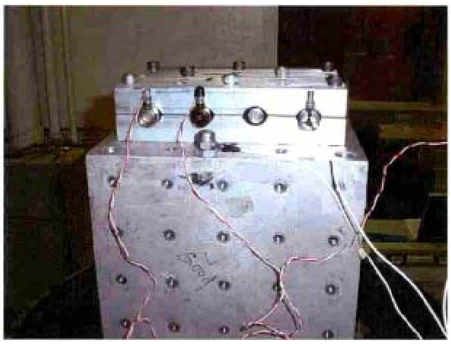
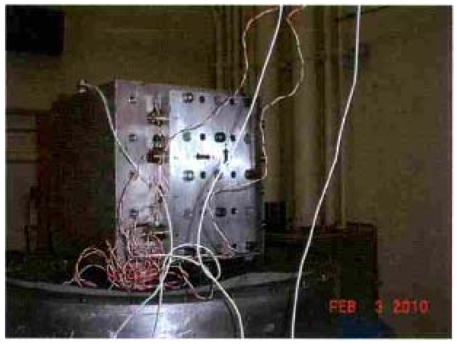
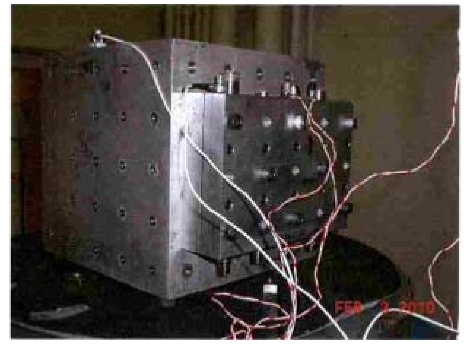
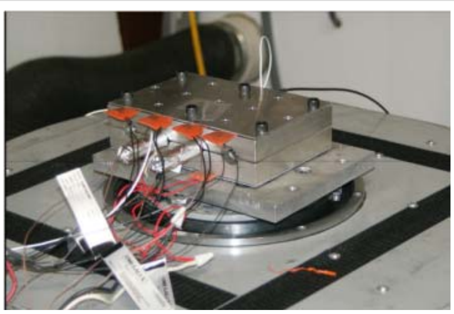
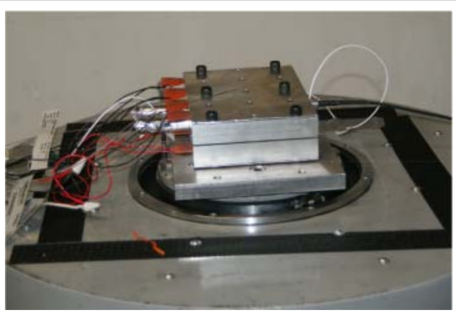
X-Axis	**Y-Axis**	**Z-Axis**
		

Table 2 shows pictures of a heated Random Vibration test setup. This particular heated test used flexible heaters with backing plates. The Y-Axis in this test was done with by rotating the transducers in the fixture.

Table 2. X, Y, and Z Axis Heated Random Vibration Test

X-Axis	**Y-Axis**	**Z-Axis**
		

Quartzdyne has found cartridge heaters inserted into the fixture to be very effective and robust. Figure 4 shows a Random Vibe test of large electrical components with differing attach methods. The fixture is outfitted with two cartridge heaters and a cartridge style thermocouple for control. The vibration level was upwards of 20 grms with temperatures in excess of 225°C.

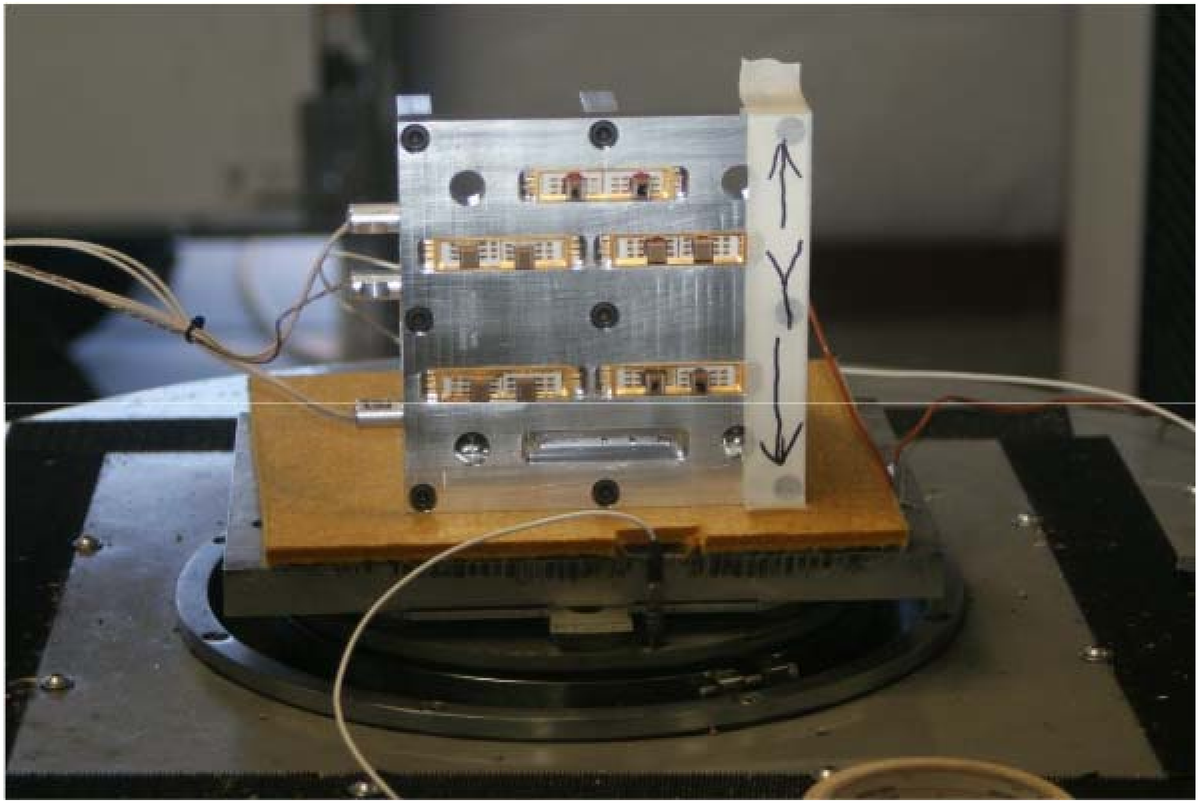


Figure 4. Hybrid Large Component Attach Heated Random Vibe Test

SINE SWEEP

A Sine Sweep test is intended to identify or isolate resonant frequencies of the structure. This test can be completed in the same setup as the Random Vibration test. During the Sine Sweep, any discernible, significant resonances receive a 10.0 g dwell for five minutes. A significant resonance has historically been defined as any resonance having an amplitude ratio greater than 1.3:1. Quartzdyne pressure transducers and Hybrid circuits are fairly simple, static devices. There is very little, if any, activity below 2000 Hz. The DXB012/SPB112 series transducer, Figure 3, has a Hybrid circuit carrier which is cantilevered from the electrical feedthru. In an unsupported condition, it will resonate at around 700 Hz, however the resonance has shown to not affect the performance of the transducer.

40 G LOW LEVEL SHOCK

The intent of a low level shock, such as a 40 g shock, is to induce further fatigue in the structure. In addition, downhole drilling conditions often comprise repetitive or cyclical shock events. The 40 g test makes a reasonable attempt at partially simulating downhole drilling conditions. Quartzdyne will typically run the Sine Sweep test, immediately move into the Random Vibration test, or vice versa, and then end with the 40 g Shock Test all in the same test setup. As indicated earlier 20 bi-directional shocks are applied in each of the three axes, for a total of 120 shocks.

500 G DROP SHOCK

Drop Shock or Drop Testing at Quartzdyne has historically been defined as a 500 g two (2) ms half-sine pulse with 25 drops per axis. Currently we continue to execute this test, however it is also being reviewed against more accurate methods. For example, the aerospace industry has long since moved away from a simple "half-sine" type of definition to the Shock Response Spectra definition. This enables the definition of Shock to more accurately represent the actual shock environment. Although convenient and easily communicated, a perfect half-sine is a much over simplified definition of an actual Shock transient event. The drawback to Shock Response Spectra is defining the curve from the beginning. It's not a difficult analytical exercise once you have data to define it. The problem is getting the data. Quartzdyne is, for the most part, in the dark on actual measured downhole shock and vibration. With a real time history of a shock event, the Shock Spectra can be derived and then an appropriate test can be built to mimic the environment, much like a Random Vibration test. This lack of data is one prominent reason why Highly Accelerated Life Testing (HALT) is becoming increasing popular, especially in the design phase, which will be discussed in the next section.

In the short term Quartzdyne will continue the 500 g Drop Shock until a Shock Response Spectra can be developed with g levels that have reasonable merit. Nonetheless it has proved to be a valuable contributor in assessing product ruggedness.

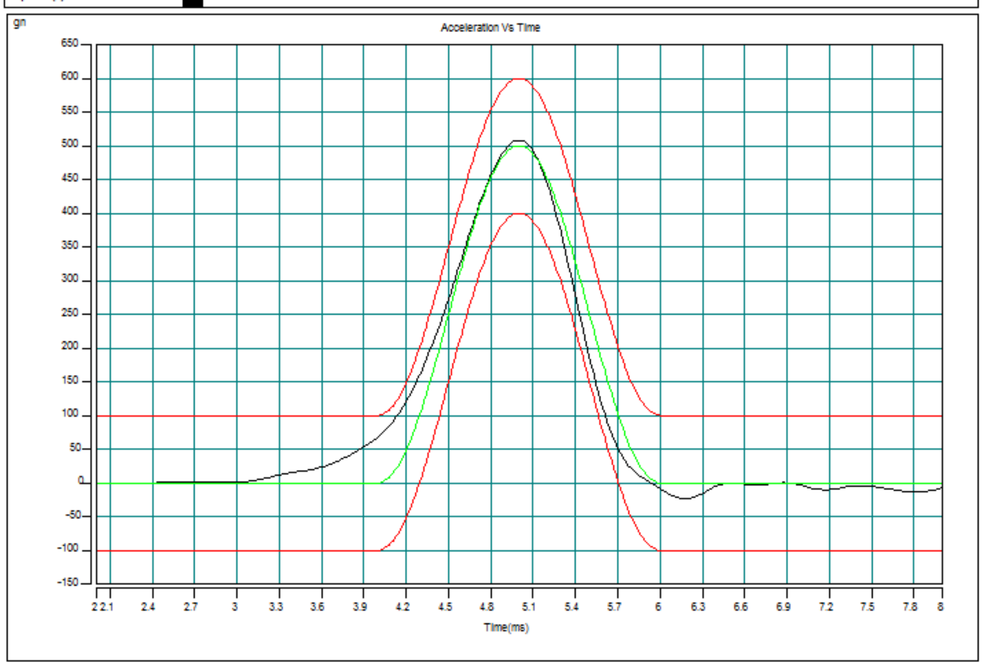
Figure 5 below shows a typical Drop Shock test being performed with Quartzdyne pressure transducers. The test requires an experienced operator to use the appropriate amount of padding or damping material to shape the half sine pulse. The machine uses a pneumatic piston to vertically lift the device under test and then accelerate downward, rapidly, onto a padded, fixed base. The machine is instrumented with an accelerometer and data acquisition system in order to feedback the shock pulse. This allows the pulse to be tuned and the damping adjusted accordingly.

Figure 5. Quartzdyne Transducers Mounted on Drop Shock Machine for 500 g Shock Test

Figure 6 below shows the respective shock pulse with error bands.

Acceleration Vs Time

Signal Name	gn	ms	cm/s	Low Pass Filter (Hz)	Max. gn	Min. gn
Input1(t)	508.15	1.94	517.17	2000.00	508.15	-23.38



Shock: 500G Duration: 2 mS Shock No. : 25

Figure 6. Shock Pulse Output.

HALT

HALT is rapidly becoming an industry standard for exposing product weaknesses early on in the design phase. As was mentioned earlier, it has proven to be a valuable testing process, in many industries, because this type of testing doesn't rely on field data to define the environment. During HALT, the product (while powered or under operation) is subject to rapid, extreme thermal cycling or increasing levels of random vibration, or commonly both at the same time, until a failure is observed. Both operational and destructive failures can be considered. Operational failures would be a condition where the product stops working during certain conditions, but returns to normal operation as the environment returns to a more benign state.

In 2011 and 2012 Quartzdyne performed HALT at two different vendors, respectively. (There are no real standard test levels with HALT, therefore it can vary from vendor to vendor.) Figure 7 shows the test setup for the HALT that was performed in 2011.

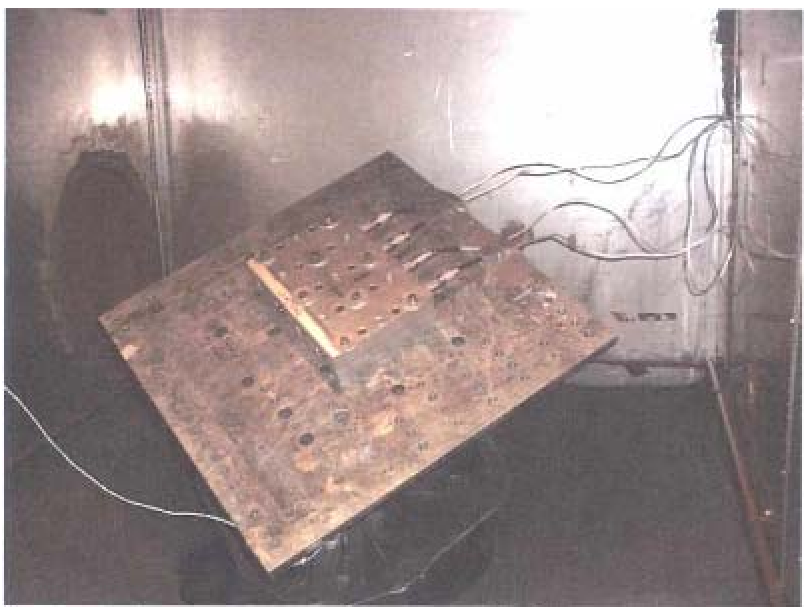


Figure 7. HALT Setup - Random Vibration on Skewed Fixture in Large Thermal Chamber.

At this particular vendor all vibration is normally performed on a skewed fixture in order to subject three axes with acceleration at the same time. The skewed fixture was used initially but subsequently broke during the test, and the remainder of the test had to be done bolted directly to the shaker and consequently only vibrated in a single axis. The approximate test environments the transducers were subject to, in order of execution, are as follows:

1. Thermal Shock: -35°C to 165°C, two cycles with a ramp rate of 30°C/min with a one hour soak at the low and high temperatures.
2. Random Vibration with Thermal Cycling: -35°C to 165°C, three cycles with a ramp rate of 30°C/min.
   a. During each of the three thermal cycles, there was a one hour soak at the high and low temperatures.
   b. The last 15 minutes of each one hour soak (at the low and high temperatures) the transducers were subject to Random Vibration.
      i. First cycle was 10-2000 Hz @ 6 grms
      ii. Second cycle was 10-2000 Hz @ 8.0 grms
      iii. Third cycle was 10-2000 Hz @ 11.5 grms
3. Heated Random Vibration: 165°C, 10-2000 Hz @ 12 grms, one hour, skewed fixture
4. Heated Random Vibration: 165°C, 10-2000 Hz @ 15 grms, two hours, single axis, fixture directly on slip table.

The units were powered during these tests and operated normally during the full test.

It is probably worth mentioning a few notes about these particular tests. When no failure was observed after Item 2 above, it was decided to carry out a final test to try and get something to fail. Item 3 was then executed. The oven was set to 165°C and the vibration level bumped to 20 grms. The shaker was incapable of holding this level for more than a few minutes. Ultimately the vibration level was set to 12 grms, on the skewed fixture. After an hour of testing the skewed fixture completely broke in half, which was alluded to previously. Item 4 was then executed. The skewed fixture had to be removed and the test continued in a single axis for two hours at 15 grms. After two hours, the cables, which were powering the units, catastrophically failed. It was decided to terminate the test. Back at Quartzdyne's facility, with new cables, the transducers were found to be operating normally.

QUARTZDYNE DROP TEST

Quartzdyne, during the design phase, will quite often employ an internal drop test to assist in the overall strength and ruggedness of new component designs for both transducers and hybrid circuits. The machine has a vertically driven pneumatic gripper which can lift and drop a test fixture anywhere from a few inches to nearly four feet high. The impact surface, by default, is a thick, aluminum base plate. If desired, any number of materials can be added to the surface of the aluminum base plate to dampen the impact. Quite often metal to metal impact is used, i.e. no padding. The machine can be set up for automatic runs consisting of a set number of drops and drop height.